7N3
8870015.1
entered

REPORT OF FINDINGS: KENAI NATIONAL WILDLIFE REFUGE DRILL MUD PILOT STUDY

Prepared for:

Daniel Dosier, Refuge Manager
U.S. Fish and Wildlife Service
Kenai National Wildlife Refuge
Kenai, Alaska

By:

Rodney Jackson
Contaminant Biologist

Approved by:

David McGillivary, Field Supervisor
U.S. Fish and Wildlife Service
Ecological Services Anchorage
605 W. 4th Avenue Room 62
Anchorage, Alaska 99501

June, 1990

APT 223

INTRODUCTION

During the last several decades, the northern portion of the Kenai National Wildlife Refuge has been the site of extensive oil and gas exploration and production. Production wells and abandoned wells exist; most have associated with them a covered and rehabilitated reserve pit containing well cuttings and drilling mud wastes.

During drilling operations the pits are used for storage of drilling fluids, cuttings, produced waters, and well pad runoff water. Volumes of drill fluids are variable, but approximately 500 barrels of mud are required for each 1,000 feet drilled. Oil wells on the refuge average about 11,000 feet in depth. Bentonite, barite and other relatively inert materials comprise the bulk of the drilling fluids. Hundreds of additives are potentially available for use in the drilling fluids, some of which are toxic to flora and fauna. Sundry salts can originate from drilling fluid additives or subsurface formations; in concentrated form these salts are potentially damaging to flora and fauna. Although these additives and salts may comprise a small (relative) proportion of the total drilling fluid volume, many are known to be acutely or chronically toxic including bactericides, lignosulfonates, emulsifiers, hydrocarbons, and metals.

A nationwide study of drilling mud use and problems associated with waste disposal was conducted by the U.S. Environmental Protection Agency (EPA, 1987); a statewide survey of drilling mud use and disposal problems was conducted by the Alaska Department of Environmental Conservation (1984). These reports demonstrate a principal point of concern and controversy revolves around the fate of potentially harmful components following burial of muds in the reserve pit. Many reports conclude that the bentonite left in the pits during rehabilitation acts as a built-in barrier to leaching - presumably a consequence of bentonite's absorption and adsorption characteristics. Notwithstanding, there are instances where drill mud components have been detected in soils and water bodies close to reserve pits (EPA, 1987). Frequently, the mechanism of their transferral (leaching, breaching, etc.) is unknown. Often, land managers require the application of a layer of fresh/unused bentonite over filled pits - thus utilizing its characteristics to prevent excess rainfall from entering the subterranean pit. (Prior to filling in reserve pits with stockpiled overburden, the Kenai National Wildlife Refuge follows a standard procedure: pit contents are well mixed by water or air pressure; a vacuum truck removes all supernatant liquids capable of being vacuumed; and these materials are disposed in approved injection wells or at sites approved by the State of Alaska.)

Given the (1) complexities and controversies regarding site-specific waste disposal problems, (2) preliminary assessment requirements for federal facilities in the Superfund Amendments and Reauthorization Act of 1986, and (3) Kenai National Wildlife Refuge resources that could be affected by subterranean transferral outside the reserve pits, this survey was undertaken to determine if evidence exists that drill mud pit materials have migrated to soils adjacent to reserve pit locations.

Bob Richey, from the Kenai National Wildlife Refuge, and Rodney Jackson, from the Ecological Services Anchorage office, conducted the field efforts; Mr. Jackson interpreted the data and authored this report.

Study Area

Figure 1 shows the general location of the Kenai National Wildlife Refuge and the Swanson River Field, which covers approximately 14 square miles of the refuge surface. Locations of the sampled well pads are indicated in Figure 2. Table 1 lists the specific locations of sampling points relative to the well head of a given pad.

Site Selection

All active and abandoned well areas on the refuge were initially considered for possible inclusion in the study effort. Several criteria were utilized to pick the well sites to be included in the initial survey: topography, soil type, nearness to surface water, well age, and accessibility. During final stages of project planning, it became evident that accessibility of sampling points to heavy equipment (backhoe) would be the major criterion determining initial sampling points. The need for a backhoe is a consequence of the predominance of unconsolidated glacial deposits which overlie most of the area. Sampling by (power) drilling was ruled out due to cost. The use of a backhoe precluded sampling on steep slopes or in wetlands distal to a well pad. This was not a significant constraint given that the objective of the initial effort was to determine if evidence existed that drill mud components had leached a relatively short distance from well pads. The selection of valid control sites was impractical due to the proximity of adjacent well pads and the lack of preliminary data. Ideally, each set of samples from a given pad should have a separate control. However, it was not known if, how far, or in which direction(s) materials may have leached. Rather than taking control samples a significant distance away from the Swanson River Field and assuming they were valid for all the sites, the project leaders chose to compare results of this study to background data that were previously collected for other contaminant studies.

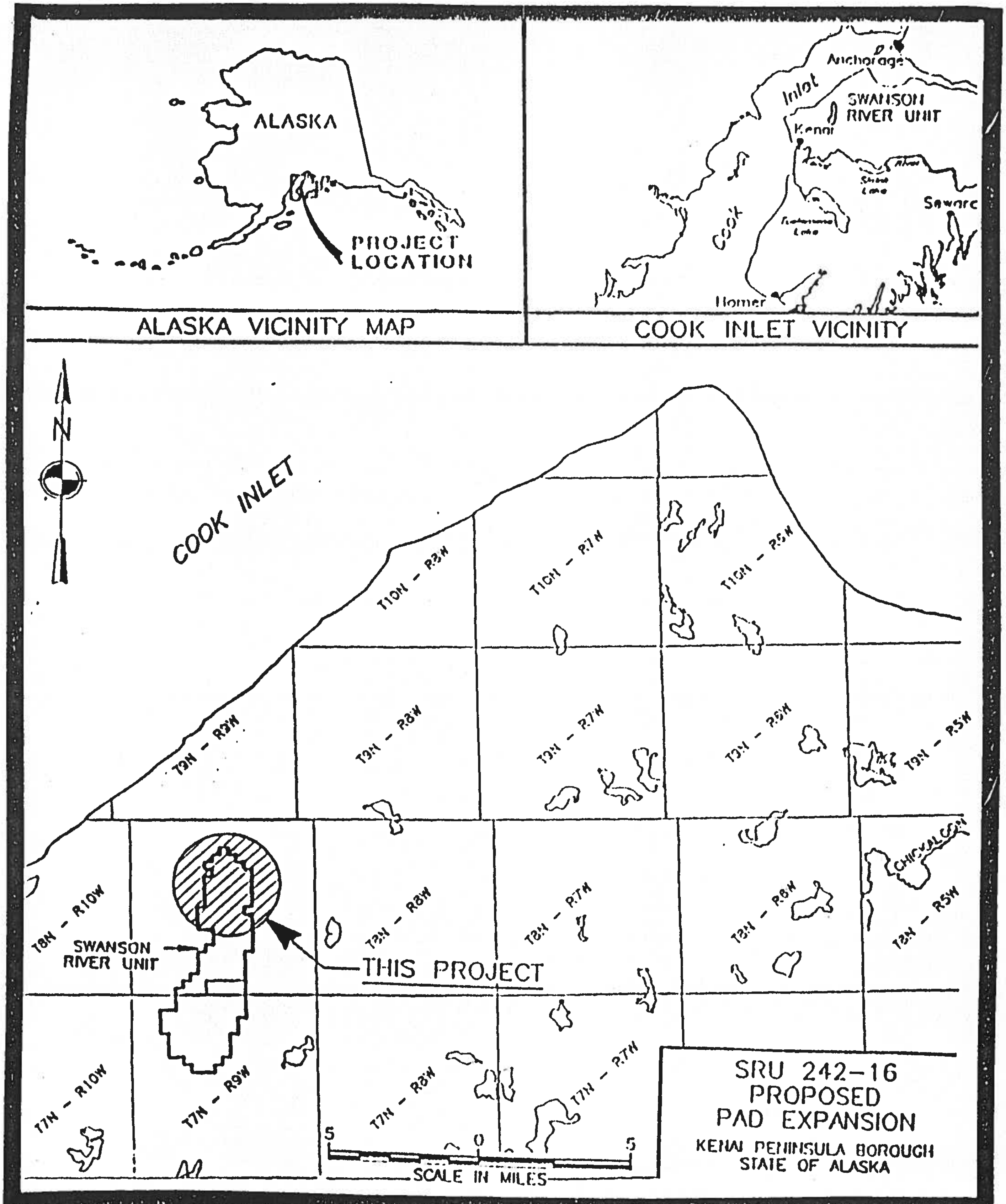

Figure 1. Study Site Location

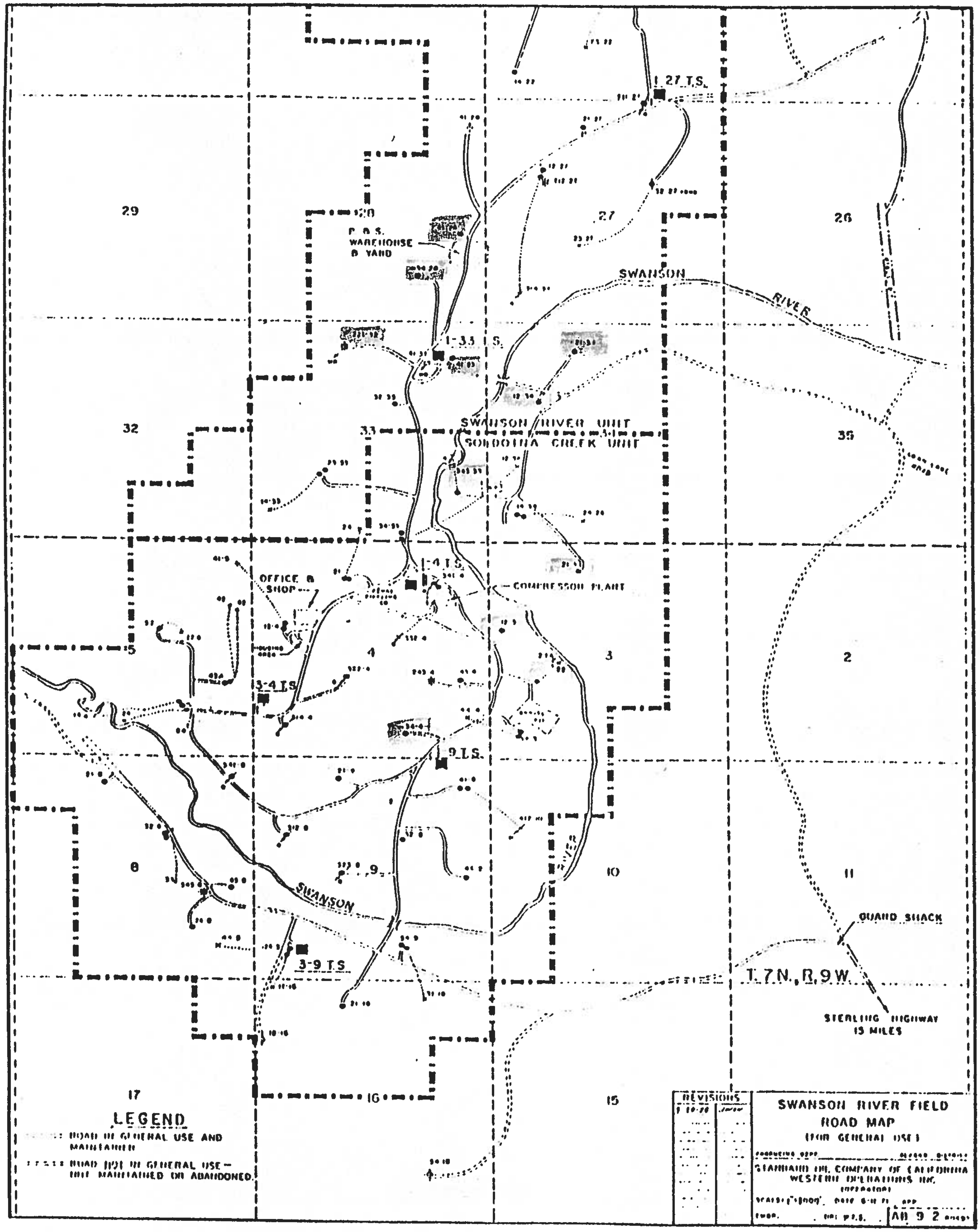

Figure 2. Location of Sampled Well Pads

Table 1. Sample Site Locations

Sample	Well No.	Exact Location[a]	Sample Depth(ft)
KR-1	SCU 34-4	190; 284°	8
KR-2	SCU 34-4	285; 230°	9
KR-3	SCU 34-4	156; 150°	10
KR-4	SRU 43-28	170; 283°	3
KR-5	SRU 43-28	175; 44°	7
KR-6	SRU 43-28	210; 10°	8
KR-7	SRU 34-28	115; 210°	5
KR-8	SRU 34-28	90; 334°	7
KR-9	SRU 34-28	115; 166°	6
KR-10	SRU 221-33	170; 180°	13
KR-11	SRU 221-33	135; 140°	14
KR-12	SRU 221-33	120; 70°	15
KR-13	SRU 41-33	250; 162°	12
KR-14	SRU 12-34	195; 208°	12
KR-15	SRU 12-34	115; 128°	13
KR-16	SRU 12-34	190; 310°	12
KR-17	SRU 12-34	190; 310°	6
KR-18	SRU 21-34	160; 180°	7
KR-19	SRU 21-34	195; 214°	8
KR-20	SRU 21-34	180; 340°	8
KR-21	SCU 343-33	170; 281°	8
KR-22	SCU 343-33	170; 286°	7
KR-23	SCU 343-33	180; 152°	4
KR-24	SCU 343-33	245; 168°	8
KR-25	SCU 343-33	175; 240°	14
KR-26	SCU 21-3	200; 222°	11
KR-27	SCU 21-3	190; 174°	13
KR-28	SCU 12-3	270; 316°	13
KR-29	SCU 12-3	220; 272°	13
KR-30	SCU 13-3	215; 134°	12

[a] First number is distance (ft) from wellhead; second number is compass heading (magnetic north)

Field Procedures

Once a sample site was chosen (criteria discussed above), a backhoe excavated a trench whose width was one-to-two shovel widths, depending on the texture of the substrate. Trench depth extended to the maximum reach of the backhoe (approximately 20 feet), or to the water table, whichever was less. A composite sample was formed by pooling three discrete samples from near the trench bottom. Care was taken to avoid soil which contacted the backhoe shovel. Plastic sample containers and implements were utilized. Thorough washing of implements prevented cross-contamination. All samples were properly labelled and kept refrigerated/frozen prior to analyses.

Analyses

Standard techniques of atomic absorption and inductively coupled plasma spectrometry were utilized by the Research Triangle Institute to determine concentrations of metals. The quality assurance report of the U.S. Fish and Wildlife Service's Patuxent Laboratory stated that the accuracy of all analyses was acceptable; however, the precision for the analyses was lower than would normally be expected.

RESULTS

As discussed earlier, a variety of drill mud components are potentially toxic, including non-essential trace metals. In addition, chromium and barium concentrations can be useful indicators of drill mud leaching. Complete sets of raw data are on file at the Kenai National Wildlife Refuge and the Ecological Services Anchorage offices. Table 2 displays the ranges of values for relevant analytes.

Data Interpretation

The process of interpreting chemical analyses is aimed at addressing the question "Do the sample data indicate a problem exists?" In its simplest form this act would appear to consist of comparing each sample datum with a list of action levels or threshold levels (= criteria), above which a problem - albeit undefined - exists. Indeed, this would be ideal. However, a variety of problems impede this approach.

In the cases of water and soil/sediment, the total amount of a chemical reported for a sample is not synonymous with the amount that is (biologically) available. The latter is strongly influenced by a complex suite of physical, chemical and biological factors (e.g. pH, Eh, hardness, alkalinity, salinity, concentration of organic matter, texture). One never has all relevant information for each sample that would allow adjustment of calculated values prior to comparison with a list of criteria

Table 2. Trace Metal Concentrations From Kenai National Wildlife Refuge Subsurface Soil Samples (n=30)

Element	Range (ppm)
Arsenic	1.9 - 22.0
Barium	92.6 - 1030.0
Boron	ND - 60.8
Cadmium	ND - 1.7
Chromium	26.2 - 86.9
Manganese	157.0 - 787.0
Mercury	ND - 0.6
Nickel	12.2 - 54.9
Selenium	ND - 1.6
Strontium	14.1 - 252.0
Vanadium	51.2 - 136.0
Zinc	36.1 - 105.0

(Long and Morgan, 1990; Shea, 1988).

In the case of tissue samples, a different criterion may exist for each species, as well as the particular tissue within that species (e.g. liver vs. kidney vs. muscle vs. whole body homogenate). Moreover, a sublethal criterion (e.g. avoidance, impaired growth, impaired reproductive success) is much lower than a criterion for safe consumption levels or acute mortality. These and other problems with developing a single set of rigid criteria are thoroughly discussed in Long and Morgan (1990) and Soholt,et al (1981). Nevertheless, an arbitrary set of criteria has been subjectively constructed by amalgamating a variety of information including: EPA's water quality criteria; review papers/series that offer lists of "action levels"; U.S. Food and Drug Administration's action levels for poisonous or deleterious substances in human food; World Health Organization's list of water quality criteria; and sundry literature dealing with some sort of biological effect of one, a few, or a group of individual chemicals. As many of the above sources as time allowed were reviewed prior to finalizing the criteria (Appendix A).

The approach to interpretation consists of a 4-step process, essentially comparing each laboratory-reported value to a series of screens:

(1) Background or control samples taken from the study area
(2) The subjective set of criteria (Appendix A)
(3) Literature values listing averages and ranges for Alaska (Gough, et al, 1988)
(4) Literature values listing averages and ranges on a worldwide basis. (Fortescue, 1980)

In general, we did not consider a sample value problematical unless it exceeded one order of magnitude of the appropriate screen(s). This is a common strategy designed to provide a buffer for a variety of sources of inherent variance, principally site specificity and laboratory methodology.

Table 3 displays the ranges of values utilized for comparison with refuge samples. Control (background) samples taken from previous studies on the Kenai Peninsula (or Alaska-wide samples) are most useful. However, boron and selenium were not analyzed in those studies; average concentrations of the earth's crust were thus included for comparison.

Most of the study data fall within the ranges of background data. Exceptions (for individual samples) exist for boron, selenium, cadmium, chromium, nickel, and zinc.

Nineteen boron analyses exceed the average concentration of the earth's crust (10.0 ppm), the only available value for comparison. Site-specific background concentrations are unknown, and the subjective criterion (Appendix A) of 100 ppm exceeds all sample data. Thus boron does not appear to be unduly elevated.

Table 3. Trace Metal Concentrations in Soils From Background Samples (n = variable)

Element	Range	Source[a]
Arsenic	5.3 - 27.7 (12)	A + B
Barium	39.0 - 3100.0 (437)	C
Boron	10.0	D
Cadmium	ND - 0.2 (6)	B
Chromium	15.3 - 41.4 (12)	A + B
Manganese	<200. - 4000.0 (416)	C
Mercury	ND - 1.8 (6)	B
Nickel	10.6 - 36.1 (12)	A + B
Selenium	0.09	D
Strontium	21.0 - 760.0 (437)	C
Vanadium	11.0 - 490.0 (437)	C
Zinc	20.8 - 67.2 (12)	A + B

[a] A = Alaska Department of Environmental Conservation. 1989. Sterling Special Waste Site Investigation. 84 pp.

B = Ecology and Environment, Inc. 1986. Data Presentation Report, Swanson River Field, Kenai National Wildlife Refuge. (unpaginated).

C = Gough, L. P., et al. 1988. Element Concentrations in Soils and Other Surficial Materials of Alaska. U. S. Geol. Survey Prof. Paper 1458. 53 pp.

D = Goldschmidt, V. M. 1954. Geochemistry. Clarendon Press, Oxford. 234 pp. (only average amounts in Earth's crust are presented)

Selenium was detected in only two samples, both of which exceed the average concentration of the earth's crust (0.09 ppm), the only available value for comparison. However, the analyses' detection limit of 0.2 ppm exceeds the screen also. The selenium subjective criterion (15.0 ppm) for potential problems is not exceeded by either sample. Thus selenium is not of concern.

Cadmium concentrations exceed the background range in every sample in which it was detectable (9 of 30 sites). However, the detection limit for cadmium for the present study (0.7 ppm) is greater than the background range (analyzed by more sophisticated methodology), and no sample value exceeds the subjective criterion (Appendix A) of 6.0 ppm. Hence, cadmium, although possibly elevated, is not considered a contaminant problem.

Chromium analyses exceed the background range in nearly all the sites. The highest sample concentration was about twice the high background concentration (86.9 ppm vs. 41.4 ppm). The subjective criterion (Appendix A) of 37.0 ppm is the low end of a range from "contaminated soils" (Eisler, 1986). Thus, although a conservative criterion is used and the chromium concentrations are not extreme at any site, elevated chromium should be viewed cautiously. Because chromium is a common component of drill muds, elevated levels may be indicative of some degree of translocation. It should be noted that barium (another potential indicator of drill mud migration) in all samples fell within the range listed for Alaskan soils. However, that range does encompass virtually two orders of magnitude. This wide range is not as precise a screen as one would expect from site-specific controls, which were not available. In summary, since no refuge chromium concentration exceeds the background (or subjective criterion) by an order of magnitude, the degree of concern remains relatively low at this time. Additional site samples (especially further from potential sources) and control samples would delineate any cause for serious concern.

Nickel concentrations in seven samples exceed the background range. However, no sample exceeded the high end of the range by a factor of two. The subjective criterion for nickel (Appendix A) is 49.0 ppm, and is considered conservative. This value was exceeded by two samples, but only slightly. In general, the sample nickel concentrations appear to be of minor concern even though some of them are at the high end of the background range.

Zinc concentrations exceed the background range in fourteen samples; however, in no case is the concentration twice the high value for the range. Moreover, the zinc subjective criterion (200 ppm) for potential problems is not exceeded. Therefore, although some of the sites appear to have relatively high zinc concentrations (compared to background), they are of little concern.

CONCLUSIONS AND RECOMMENDATIONS

Several of the trace metals appear to be in relatively high concentrations, but only in some samples. In no case is gross contamination evident for any element. This finding is in accord with results of a previous study (Ecology and Environment, Inc., 1986). If individual samples are considered to be three separate indicators of leaching (or other contaminant problems) for a given well, the most suspect of all well pads examined is SRU 21-34. Collectively, it yielded the highest concentration found for chromium, manganese, nickel, vanadium and zinc. Nevertheless, it must be emphasized that when metals are considered separately, in no case does there appear to be cause for great concern. Given the relatively high concentrations of chromium (and possibly barium) found at the examined wells, it may be prudent to conduct additional sampling to determine if these levels are due to a slight degree of leaching, or are merely representative of naturally high and variable background levels for the area. Prior to additional sampling, your staff must submit a study plan to the Regional Contaminants Coordinator to secure funding.

REFERENCES

Alaska Department of Environmental Conservation . 1984. Survey of Drilling Mud Use and Disposal, Alaska. Unpublished Report. Unpaginated.

Eisler, R. 1986. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.6). 60 pp.

Fortescue, J. A. C. 1980. Environmental Geochemistry: A Holostic Approach. Springer - Verlag, New york. 347 pp.

Gough, L. P., Severson, R. C. and H. T. Shacklette. 1988. Element Concentations in Soils and Other Surficial Materials of Alaska. U.S. Geol. Survey Prof.Paper 1458. 53 pp.

Long, Edward R. and L. G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the national status and trends program. NOAA Tech. Mem. NOS OMA 52. 175 pp.

Shea, D. 1988. Developing national sediment quality criteria. Environ. Sci. Technol. 22(11): 1256 - 1261.

Soholt, L. F., et al. 1981. Coal Combustion Waste Manual: Evaluating Impacts to Fish and Wildlife. U.S. Fish and Wildlife Service, Biological Services Program, National Power Plant Team, FWS/OBS-81/05. 150 pp.

U. S. Environmental Protection Agency. 1987. Technical Report: Exploration, Development, and Production of Crude Oil and Natural Gas. EPA 520-SW-87-005.

APPENDIX A

U.S. FISH AND WILDLIFE SERVICE
ECOLOGICAL SERVICES ANCHORAGE

ACTION LEVELS FOR SELECTED TRACE ELEMENTS AND HEAVY METALS

Appendix A. Action Levels : Metals

ELEMENT	CRITERIA[a]	
	Water[b]	Soil/Sediment[b]
Aluminum	400.0 (F);10.(M)	81000.(F)
Antimony	0.6 (F)	9.0
Arsenic	0.1 (F); 0.02 (M)	64.0
Barium	------	700.
Beryllium	50.0 (F)	15.0
Boron	10.0 (F)	100.
Cadmium	0.003 (F); 0.009 (M)	6.0 (F); 9.0 (M)
Chromium	0.03 (F); 1.2 (M)	37.0 (F); 128.(M)
Copper	0.01 (F); 0.005 (M)	310.
Lead	0.02 (F); 0.01 (M)	50.0 (F); 104.(M)
Manganese	7.0 (F); 2.0 (M)	670.
Mercury	0.002 (F); 0.0003 (M)	20.0 (F); 1.0 (M)
Molybdenum	50.0 (F)	100.
Nickel	0.3 (F); 2.0 (M)	100.
Selenium	0.3 (F); 0.4 (M)	15.0
Silver	0.001 (F); 0.01 (M)	2.1
Tin (inorganic)	0.05 (F); 0.3 (M)	200.
(tributyl)	0.00001 (F)	---
Vanadium	1.0 (F); 1.0 (M)	---
Zinc	20.0 (F); 5.0 (M)	200. (F); 267. (M)

[a] All concentrations are in ppm. Subjective criteria were chosen using best professional judgment after consulting references listed at the end of this appendix. In general, a sample value greater than 10 times a criterion can be cause for concern.

[b] (F) = freshwater; (M) = marine

Fish and Wildlife Service
Ecological Services Anchorage
Action Levels Bibliography

Cleland, J. G. and G. L. Kingsburg. 1977. Multimedia Environmental Goals for Environmental Assessment. Vol II. MEG Charts and Background Information. EPA 600/7-77-1366. U.S. Environmental Protection Agency, Washington, D.C.

Day, John W., Jr., Hall, C. A., Kemp, W. M. and A. Yanez-Arancibia. 1989. Estuarine Ecology. John Wiley and Sons, New York. 543 pp.

Eisler, R. 1989. Molybdenum Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.19). Patuxent Wildlife Research Center, Laurel, Maryland. 61 pp.

Eisler, R. 1989. Tin Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.15). Patuxent Wildlife Research Center, Laurel, Maryland. 83 pp.

Eisler, R. 1988. Arsenic Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.12). Patuxent Wildlife Research Center, Laurel, Maryland. 92 pp.

Eisler, R. 1987. Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.14). Patuxent Wildlife Research Center, Laurel, Maryland. 134 pp.

Eisler, R. 1987. Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.10). Patuxent Wildlife Research Center, Laurel, Maryland. 90 pp.

Eisler, R. 1986. Chromium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.6). Patuxent Wildlife Research Center, Laurel, Maryland. 60 pp.

Eisler, R. 1985. Cadmium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.2). Patuxent Wildlife Research Center, Laurel, Maryland. 46 pp.

Eisler, R. 1985. Selenium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.5). Patuxent Wildlife Research Center, Laurel, Maryland. 57 pp.

Farm Chemicals 1989. Farm Chemical Handbook. Meister Publishing Company, Willoughby, Ohio. 375 pp.

Fortescue, J. A. C. 1980. Environmental Geochemistry: A Holistic Approach. Springer - Verlag, New york. 347 pp.

Goldschmidt, V. M. 1954. Geochemistry. Clarendon Press, Oxford. 234 pp.

Gough, L. P., Severson, R. C. and H. T. Shacklette. 1988. Element Concentrations in Soils and Other Surficial Materials of Alaska. U.S. Geol. Survey Prof.Paper 1458. 53 pp.

Gough, Larry P., H. T. Shacklette, and A. A. Case. 1979. Element concentrations toxic to plants, animals, and man. Geol. Survey Bull. 1466. U.S. Govt. Printing Office. 80 pp.

Hem, J. 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water-Supply Paper 2254. Alexandria, VA. 263 pp.

Jenkins, D. W. 1980. Biological Monitoring of Toxic Trace Metals. Volume I, Biological Monitoring and Surveillance. U.S. EPA Office of Research and Development. Las Vegas, NV. EPA-600/3-80-089, NTIS PB81-103475. September. 215 pp.

Jenkins, D. W. 1980. Biological Monitoring of Toxic Trace Metals. Volume 2, Toxic Trace Metals in Plants and Animals of the World. Part I. U.S. EPA Office of Research and Development. Las Vegas, NV. EPA-600/3-80-090, NTIS PB81-103483. September. 503 pp.

Jenkins, D. W. 1980. Biological Monitoring of Toxic Trace Metals. Volume 2, Toxic Trace Metals in Plants and Animals of the World. Part II. U.S. EPA Office of Research and Development. Las Vegas, NV. EPA-600/3-80-091, NTIS PB81-103491. September. 478 pp.

Jenkins, D. W. 1980. Biological Monitoring of Toxic Trace Metals. Volume 2, Toxic Trace Metals in Plants and Animals of the World. Part III. U.S. EPA Office of Research and Development. Las Vegas, NV. EPA-600/3-80-092, NTIS PB81-103509. September. 290 pp.

Johnson, W., and M. Finley. 1980. Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates. U.S, Fish and Wildlife Service, National Fisheries Research Laboratory, Columbia, Missouri. Resource Pub. 137. 98 pp.

Komarovskiy, F. and L. Polishchuk. 1982. Mercury and other heavy metals in the water: migration, accumulation, and toxicity to aquatic organisms (a review). Hydrobiological Journal 5:51-62.

Lindsay, W. 1979. Chemical equilibra in soils. John Wiley and sons, New York. 449 pp.

Long, Edward R. and L. G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the national status and trends program. NOAA Tech. Mem. NOS OMA 52. 175 pp.

Mance, Geoffery. 1987. Pollution Threat of Heavy Metals in Aquatic Environments. Elsevier Applied Science, London. 363 pp.

McErlean, A. and T. Duke. 1981. On the use of indices in aquatic toxicological hazard assessment. Regulatory Toxicological and Pharmacological. 1:344-354.

National Academy of Sciences and National Academy of Engineering. 1972. Water quality and criteria. A report of the Committee on Water Quality Criteria, Environmental Studies Board. EPA R3-73-003. March, 1973. PB 236-199/6BA.

Olsen L. and K. Adams. 1984. Effects of Contaminated Sediment on Fish and Wildlife: Review and Annotated Bibliography. U.S. Fish and Wildlife Service. Washington, D.C. FWS/OBS-82/66 April 103 pp.

Pavlou, Spyros P. 1987. The use of the equilibrium partitioning approach in determining safe levels of contaminants in marine sediments. Chap. 25 in Dickson, K. L., Maki, A. W. and W. A. Brungs (Eds.), Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems. Pergamon Press, New York. 447 pp.

Sax, N. 1987. Hazardous Chemicals Information Annual, No. 2. (Editor) Van Nostrand Reinhold Co., New York. 707 pp.

Sax, N. 1986. Hazardous Chemicals Information Annual, No. 1. (Editor) Van Nostrand Reinhold Co., New York. 766 pp.

Sax, N. and R. Lewis. 1987. Hazardous Chemicals Desk Reference. Van Nostrand Reinhold Co., New York. 1084 pp.

Shea, D. 1988. Developing national sediment quality criteria. Environ. Sci. Technol. 22(11): 1256 - 1261.

Smith, J., Harte, P. and M. Hardy. 1989. Trace-metal and organochlorine residues in sediment of the upper Rockaway River, New Jersey. Bull. Environ. Contam. Toxicol. 39:465-473.

Soholt, L., Harris, V., Knight, M., Siskind, B. and D. Wyman. 1981. Coal Combustion Waste Manual: Evaluating Impacts to Fish and Wildlife. U.S. Fish and Wildlife Service, Biological Services Program, National Power Plant Team, FWS/OBS-81/05. 150 pp.

Tetra Tech, Inc. 1989. Work Plan. Remedial Investigation/Feasibility Study, Naval Air Station Adak, Adak Island, Alaska. Prepared for U.S. Navy Engineering Field Activity, Northwest, Naval Facilities Engineering Command, Silverdale, Washington. October. 114 pp.

U.S. Environmental Protection Agency. 1986. Superfund Public Health Evaluation Manual. Office of Emergency and Remedial Response. Washington, D.C. EPA/540/1-86/060 October. 175 pp.

U.S. Environmental Protection Agency. 1986. Hazardous Waste Land Treatment. Municipal Environmental Research Laboratory. Office of Research and Development. Cincinnati, Ohio. Pub. SW-874. April. 671 pp.

U.S. Environmental Protection Agency. 1979. Water-Related Environmental Fate of 129 Priority Pollutants. Volume I. Introduction and Technical Background, Metals and Inorganics, Pesticides and PCBs. Office of Water Planning and Standards, Office of Water and Waste Management. Washington D.C. EPA-440/4-79-029a. NTIS PB80-204373. December. 400 pp.

U. S. Environmental Protection Agency. 1976. Quality Criteria for Water. EPA 440/9-76-023.

19 pgs.

Fish & Wildlife Manuals

gif ID Numbers

rpt#	gif#	page #
RPT00223.AIM	<00223001.gif>	Fig. 1
	<00223002.gif>	Fig 2

L.C. mf.

Copy

P:\WP\DOCS\F&W\GIFLOG